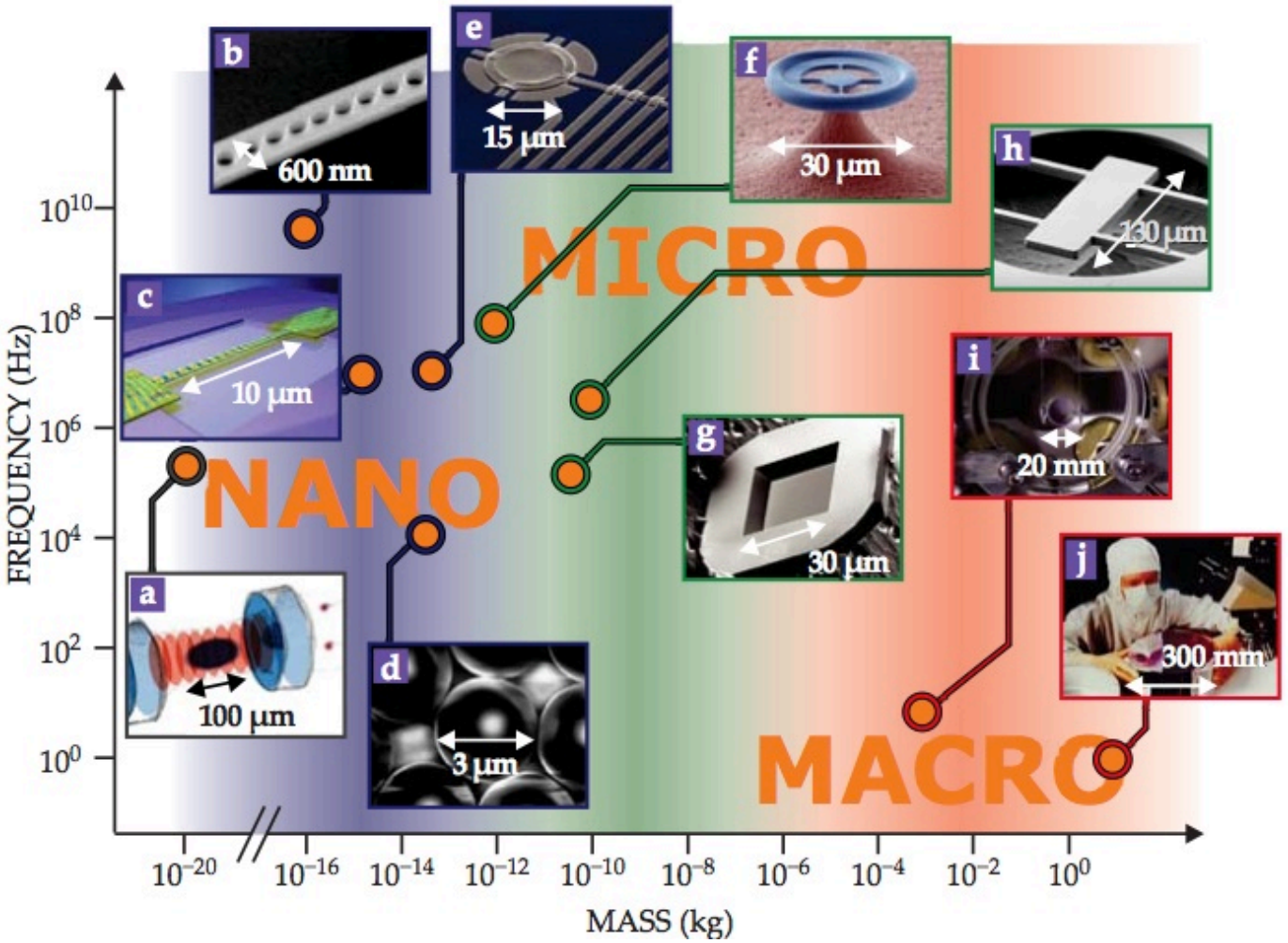
Quantum Sensing and Quantum Information Science with Mechanical Resonators



Physics Today: Aspelmeyer et al.

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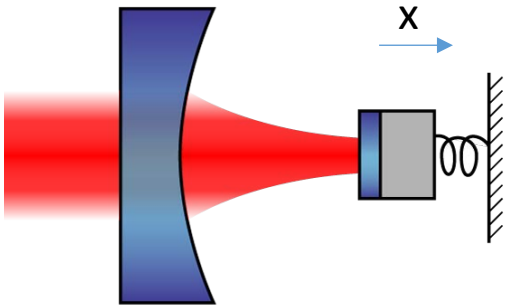
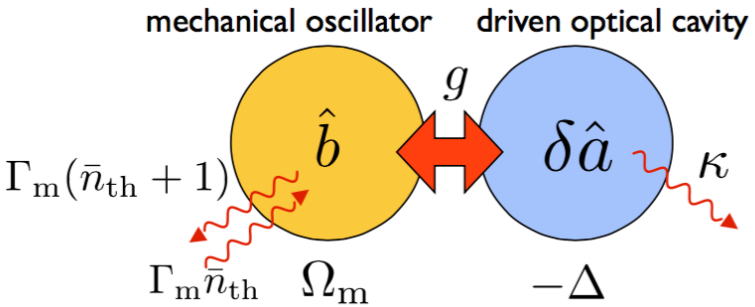
University of Colorado and NIST

Quantum cavity optomechanics

any part of EM spectrum

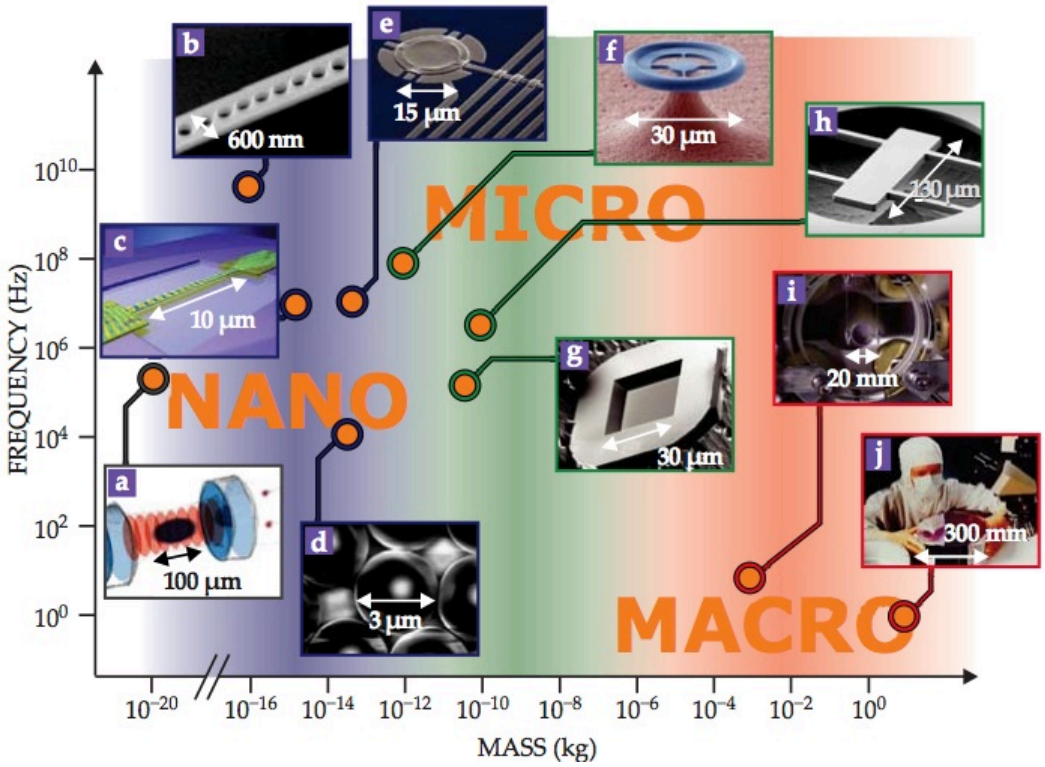
Classic quantum optics thought experiments are now reality for isolated single modes of micro and even macro objects





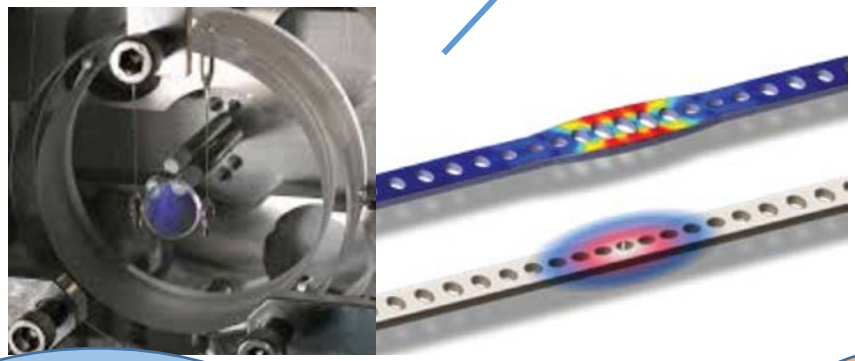
Kilogram-scale to femtogram scale

- Solid state objects
- Atoms
- Superfluid helium
- …



- Extreme force microscopy
- Interferometry at quantum noise limits and beyond

Implications for fundamental physics



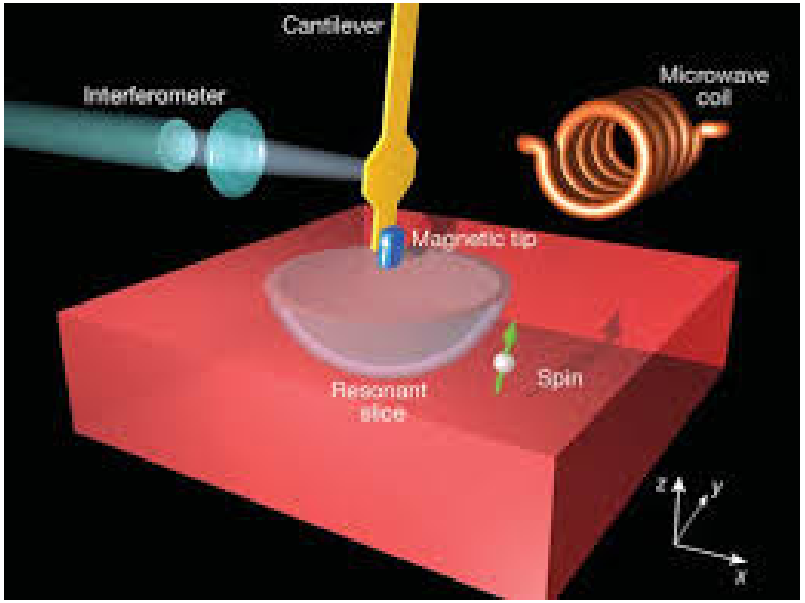
Quantum systems of mechanics and light

- Tools for hybrid quantum networks
- Quantum processing/quantum systems of photons and phonons
- Nonclassical states of mechanics

New ways of thinking about engineering challenges – optical and phononic integration

- Extreme force microscopy
- Interferometry at quantum noise limits and beyond

Example: Magnetic-resonance force microscopy
Another route to **nanoscale MRI**
Can recent technology and quantum manipulation revive this technique?



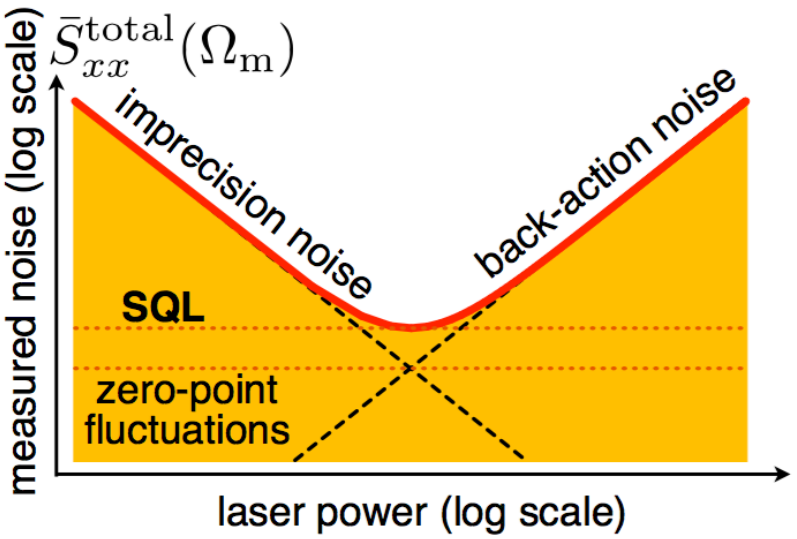
Force sensitivity scale aN/rtHz

- Extreme force microscopy
- Interferometry at quantum noise limits and beyond

How well can an interferometer **sense displacement and force**?
For typical configuration only as well as shot noise and radiation pressure noise allow.
To get around this:

- Squeezed light, variational output
- Quantum backaction evasion

Classic *example*: Advanced LIGO
But also…any newer relatives
– holometer?, dark-matter search proposals?

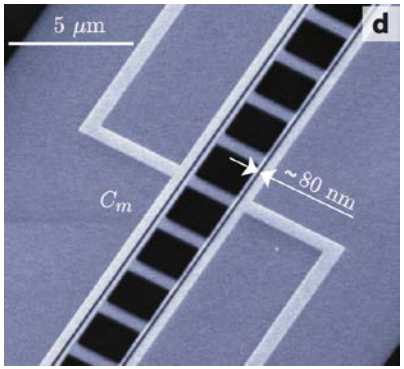


Mechanics in QIS:

Naturel niche in QIS seems to be as a **hybrid quantum processing element**

Example: Conversion between microwave and optical photons

Engineering new nonlinear optical materials (versatile Kerr media)



Optomechanical crystal with capacitive coupling to circuit

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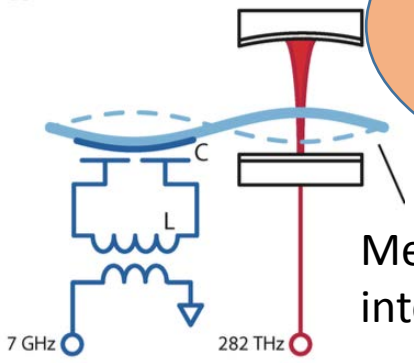
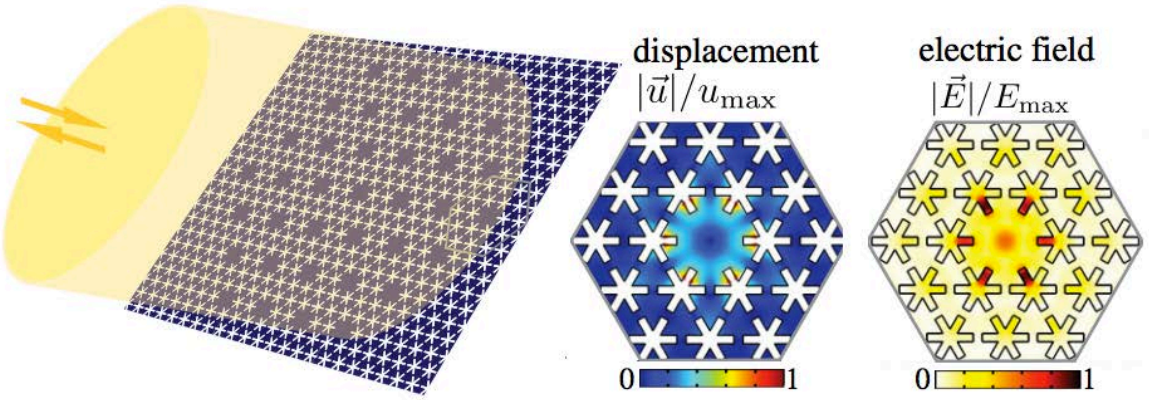


Mechanical intermediary

Manipulation at single photon and single phonon level:
Example: Optomechanical crystals



Optomechanical arrays: photon blockade regime
Hopping phonons and photons

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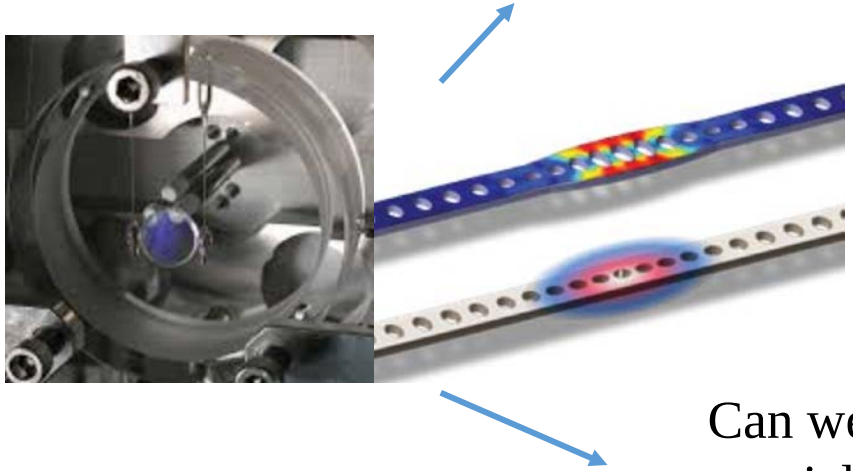
Translated to example specific questions:

Can we develop precision interferometry over wide range of frequency and mass that avoids limitations of quantum noise?

Can force microscopy enable 3D imaging at the single-molecule level?



Can we connect the many disparate and specialized hardware components of quantum information science across a broad range of frequencies?

Can we and is it of interest to study entanglement between more and more massive mechanical objects?

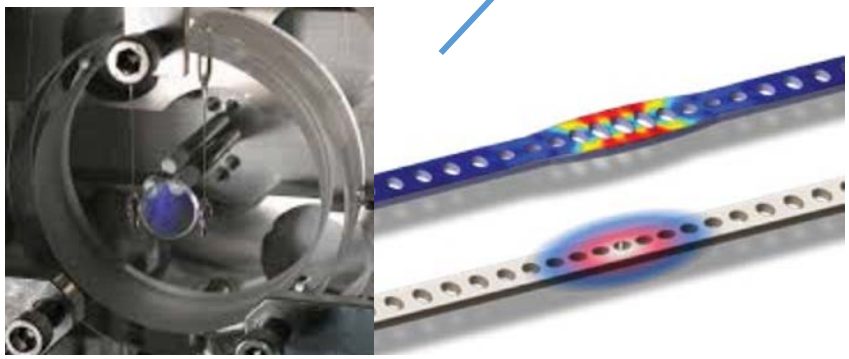
Programmatic connections:

Instrumentation sciences
Biosciences

- Interferometry at quantum noise limits and beyond
- Extreme force microscopy

High energy physics

Implications for fundamental physics



Advanced Computing
Materials Science

Tools for hybrid quantum networks
Quantum processing/quantum systems of photons and phonons
Nonclassical states of mechanics

This field often falls between traditional areas:
Not solid state physics, AMO physics, mainstream quantum processing technique